Intelligent Sensor Networks - an Agent-Oriented Approach

Björn Karlsson
Communication Research Labs Sweden AB
Varvsholmen
SE-39230 Kalmar, Sweden
+46 (0)480 423947
bjorn.karlsson@crl.se

Oscar Bäckström
Communication Research Labs Sweden AB
Varvsholmen
SE-39230 Kalmar, Sweden
+46 (0)480 423947
oscar.backstrom@crl.se

Wlodek Kulesza
University of Kalmar
SE-39182 Kalmar, Sweden
+46 (0)70 237 56 75
wlodek.kulesza@hik.se

Leif Axelsson
Ericsson Microwave Systems AB
SE-43184 Molndal, Sweden
+46 (0)70 987 63 48
leif.l.axelsson@ericsson.com

ABSTRACT

This paper describes the agent oriented programming paradigm for development of intelligent sensor networks. The case study was performed by implementing a testbed using JADE, **J**ava **A**gent **DE**velopment **F**ramework, as a basis of testing this proposed approach, and making implemental experiences of the agent paradigms maturity for dynamic wireless sensor networks. The application of the specific implementation is an **U**nattended **G**round **S**ensor **N**etwork, UGSN, for surveillance of moving targets. An intelligent sensor network in this case should consist of autonomous sensor nodes, which exchange information, reason and collaborate with each other. The UGSN should preserve energy resources and work as one unit when delivering fused and compiled sensor information to the end user.

Keywords: Unattended Ground Sensor Network, Agent Programming**,** Distributed Data Fusion, Ad hoc networks

1. INTRODUCTION

In a surveillance application scenario the situation picture from the sensor network should in many cases preferably consist of target tracks and target identities based on fused sensor information, rather than sending single and non-fused sensor readings. Since the network is decentralized, the data fusion process has to take place without the need of a central fusion node.

Decisions have to be made by the network where the fusion process spatially has to be executed. Because the targets are moving through the network and sensor information must not be broadcasted over all network nodes, the data fusion should be processed in a distributed manner. To reduce energy consumption, information in an intelligent sensor network should only be shared to nodes that can be of benefit by that specific information. This is not a trivial problem and a communication strategy must therefore exist for information dissemination between network nodes.

A sensor network with intelligent behavior is a system that can adapt to the situation, present information that is relevant for the moment and a system that has reasoning parts that are designed to function with low-level rules and work together to accomplish a high-level goal.

Focus of the intelligent sensor network has not been put on the explicit fusion algorithm but on developing a communication architecture that is suitable for distributed data fusion. With sensor data correlation and fusion, the UGSN detects targets, track movements in the area and also possibly classifies and types targets. Sophisticated and advanced sensors, in the sense of performing some degree of data processing, can with advantage be used together with more simple and low-cost sensors to achieve both target tracking and target type identification. The distributed *intelligence* of the network and fusion process must be able to easily be adjusted for new types of sensors and data entities.

2. AGENT PROGRAMMING PARADIGM

The main characteristics of an **A**gent **O**riented, AO, design are that it consists of autonomous problem-solving entities that interact with other agents using high-level communication. Regular objects communicate through simple lower level method invocations or method calls with limited range of variation in parameters. Agents communicate through a thorough declarative high-level agent communication language. Those speech acts can be informing, requesting, offering, accepting, believing, rejecting, competing, assisting and so on.

In the **O**bject **O**riented **P**rogramming, OOP, paradigm, the programming object is specified by the real object it represents by its state and the actions that can be performed by, or on, it. Similar, an agent is formally specified by its mental state consisting of its beliefs, goals, actions and ongoing interaction with other agents and its environment.

There exist numerous of different naming and terms for the properties describing an agent. Autonomy, pro-activeness, collaboration and mobility are the most important agent properties for the intelligent sensor network. *Autonomy* means that the agents have control over their own internal state and behavior. *Pro-activeness* denotes that the agent has self-starting behaviors and ability to initiate actions. The *collaborative* (or *cooperative*) behaviour means that an agent perceives its environment and other agents, and has the ability to communicate and interact/cooperate with those. *Mobility* of an agent requires the ability to migrate in a self-directed way from one host platform to another.

3. IMPLEMENTATION AND RESULTS

An intelligent ground sensor network with reasoning agents has been developed. The network is correlating sensor information and autonomously tracking targets and fusing target information. The information fusion process is made possible due to reasoning and mobile software agents and results in a higher confidence level of target entities, such as type-class and type-identification. The fusion algorithm is based on a majority voting ordinary technique, merely implemented to show the possibilities and benefits of distributed information fusion in wireless sensor networks. The network autonomously decides

when to update external applications and with what information, which results in greater situation awareness for the end user.

JADE, [5] is used as a tool for the sensor network implementation and agent runtime environment. JADE is FIPA, [3], specification compliance, open source under LGPL license and implemented in Java. The benefit of using an agent development framework results in a more mature and functional system. JADE handles the agent lifecycle, the internal agent execution and the agent communication and message handling. Due to the interaction protocols provided by the development framework, dynamic behaviours of the UGSN, such as correlation and fusion, can easily be adjusted by small means. The framework also provides all common agent tasks as message encoding/decoding, tracing, monitoring and agent thread handling. JADE makes it possible to focus even more on the business logic instead of being forced to deal with the lower communication layer and framework implementation issues. Regarding low performance systems, JADE has in projects been adjusted to be compatible with J2ME CLDC/MIDP1.0. In this configuration the memory footprint was about 100kB, [1].

The UGSN performs both decentralized and distributed data fusion. At each ground sensor, the sensor data is fused into target information corresponding to decentralized data fusion.

The collaborative and mobile properties of software agents has resulted in a mobile agent, called **T**arget**A**gent, TA. The TA is created on the host where the first sensor trig occurs. The TA is then reasoning with its neighboring nodes and correlating their sensor data in order to decide where to migrate next. The TA migrates between nodes in order to always be located close to the target it tracks. After each migration the TA is performing the fusion process in a distributed manner with available sensor information from the new hosting node. The supported interaction protocols in JADE have also made it possible for the TA to delegate sub-tasks. The TA could query other agents for assistance, e.g. ask a camera node to take a snapshot on a target and further find another sensor node to assist the camera node as a trig sensor for better timing when taking the snapshot.

4. REQUIRED IMPROVEMENTS FOR AD HOC ENVIRONMENTS

Currently the FIPA specifications have not yet been fully suitable for agents in ad hoc networks. Current FIPA abstract architecture specifies two mandatory components of an **a**gent **p**latform, AP. The first is the **A**gent **M**anagement **S**ystem, AMS, which represents the management authority of an AP and is responsible for e.g. agent life-cycle management, agent creation and deletion. The second mandatory component is the **d**irectory **f**acilitator, DF, which acts as a yellow pages directory for agent lookups. FIPA specifications do not contain descriptions for mechanisms to implement agent migration. However, JADE enables migration but only within one distributed AP.

The node hosting the AMS and DF will in a distributed AP represent a single point of failure. Using a global AMS and DF implies a heavy load on the network resources in order to maintain an updated directory of all agents.

Therefore, FIPA has to this date specified a preliminary specification of a modified AP reference model for discovery in ad hoc networks in the specifications of an Agent Discovery Service and a Discovery Middleware Specification, [2]. Each node contains a complete AP, including the AMS, meaning a node is not dependent on any other node for its agent management functionality. The AP contains an **A**gent **D**iscovery **S**ervice, ADS, by which the local agents register their services they wish to make public in the ad hoc network. The ADS searches for and/or publishes services to the network by using one or several **d**iscovery **m**iddleware, DM, available in the ad hoc network. SLP, Gnutella, Bluetooth, UPnP, Salutation and JXTA are examples on different discovery technologies. A service on a peer is found by another peer, either by a service pushing information about its presence over the network, or by a peer sending a search request through the DM. The inconsistency of found agents/services is a specific difficulty for ad hoc environments. A solution is that each registered service has a leasing time.

5. CONCLUSION

The development of an intelligent sensor network faces numerous objectives and challenges. This work has evaluated the benefits of using the agent-oriented view of software development in distributed information fusion systems.

Agents are specified by mental states such as beliefs and intentions. This way of modeling makes AO systems more capable of handling dynamic relationships, which often can be found in distributed sensor networks, than e.g. the OOP paradigm. The agent paradigm and the agent's high-level communication language together with an agent development framework, like JADE, makes it possible to realize complex distributed tasks, such as agent reasoning and sub-task delegation, by use of small means.

The agent oriented software paradigm has approved to be highly suitable in development of complex and distributed systems. The current architecture specifications of agent systems are not mature or efficient enough for ad hoc environments. However, FIPA has presented a draft for a specification of how to use discovery middleware such as JXTA in ad hoc environments to solve the need of central lookup- and management services.

6. REFERENCES

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